

## METHOD AND A DEVICE FOR PREPARING A MEDICAL LIQUID

The present invention relates to a method and a device for preparing a medical liquid.

The invention has an application in particular in the treatment of renal insufficiency, where it can be used for preparing a dialysis liquid. In this context, the invention is particularly suitable for treating patients whose internal medium presents an excess of potassium.

The kidneys perform many functions, including elimination of water, excretion of catabolites (or waste products of metabolism, such as urea and creatinine), regulation of the concentration of electrolytes in the blood (sodium, potassium, magnesium, calcium, bicarbonates, phosphates, chlorides), and regulation of the acid-base balance of the internal medium, which balance is obtained in particular through the elimination of weak acids (phosphates, monosodium acids) and through the production of ammonium salts.

In persons who have lost the use of their kidneys, since these excretory and regulatory mechanisms no longer function, the internal medium becomes charged with water and waste products of metabolism and presents an excess of electrolytes (sodium in particular), and, in general, acidosis, with the pH of the blood plasma shifting towards 7.

To remedy kidney dysfunction, the conventional practice is to treat the blood by extracorporeal circulation in a semipermeable membrane exchanger (hemodialyzer), with circulation, on either side of the membrane, of the patient's blood and of a dialysis liquid comprising the main electrolytes of the blood (chlorides, bicarbonates, sodium, calcium, potassium, magnesium) in concentrations close to those of the blood of a healthy subject. As a result of the physical phenomenon called dialysis, the molecules migrate from the liquid in which their concentration is highest to the liquid in which their concentration is lowest.

A significant electrolytic change in uremic patients is

the increase in the potassium concentration of the plasma. Now, hyperkalemia (too high a concentration of potassium) is associated with incidents linked to hyperpolarization of the membrane of the neuromuscular cells, which can result in hypokinetic arrhythmia and complete atrioventricular block. One of the objectives of dialysis treatment is therefore to eliminate the excess potassium accumulated by the patients between two treatment sessions. In accordance with the physical principle cited above, the quantity of potassium eliminated during treatment depends directly on the difference between the concentration of the potassium in the plasma and the concentration of the potassium in the dialysis liquid, which is generally fixed at a constant level, less (approximately 2 mEq/l) than the physiological level (approximately 3.5 mEq/l).

At the start of conventional dialysis treatment, a patient with hyperkalemia (whose plasma potassium concentration can be as high as 10 mEq/l) is exposed to the undesirable effects resulting from the considerable difference between the potassium concentration of his plasma and that of the dialysis liquid: this increased gradient in fact causes a substantial diffusive flow of potassium across the membrane of the hemodialyzer, which in turn causes a substantial flow of potassium across the membrane of the cells, which affects the electric potential of the membrane at rest and, consequently, the cellular excitability. As this mechanism also influences the cardiac pacemaker cells, the patient runs the risk of cardiac arrhythmia during the dialysis treatment. This phenomenon is naturally heightened in cases of cardiac weakness and can lead to a reduction in the ejection volume affecting the cardiovascular circulation.

A particular object of the invention is therefore to modify the conditions of conventional dialysis treatment, without however affecting its effectiveness, in such a way that patients with hyperkalemia are no longer exposed to the risks mentioned above.

A general object of the invention is to conceive a device and a method for preparing a treatment liquid which can be

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used for extracorporeal treatment of blood, and by means of which the concentration of two ionic substances can be adjusted separately, in particular sodium and potassium (or calcium, or magnesium).

5 According to the invention, this object is achieved by means of a method for preparing a medical liquid from a liquid, such as water, and two concentrated solutions, comprising the following steps:

- circulating the liquid in a conduit, at a flowrate  $Q_0$ ;
- 10 - injecting into the conduit, at a flowrate  $Q_1$ , a first concentrated solution containing a first ionic substance A and a second ionic substance B, the ionic substances A and B having, respectively, in the first concentrated solution, a concentration  $[Asol]$  and a first concentration  $[B1sol]$ ;
- 15 - injecting into the conduit, at a flowrate  $Q_2$ , a second concentrated solution containing the first ionic substance A and the second ionic substance B, the first ionic substance A having, in the second concentrated solution, the same concentration  $[Asol]$  as in the first concentrated solution, 20 and the second ionic substance B having, in the second concentrated solution, a second concentration  $[B2sol]$  different than the first concentration  $[B1sol]$  in the first concentrated solution;
- regulating the injection flowrate  $Q_1$  and the injection 25 flowrate  $Q_2$  of the first and second concentrated solutions in such a way that at any given time the diluted solution resulting from the mixing of the liquid and the concentrated solutions has a desired concentration  $[A_{des}]$  of first substance A and a desired concentration  $[B_{des}]$  of second 30 substance B.

According to one characteristic of the invention, the injection flowrate  $Q_1$  and the injection flowrate  $Q_2$  of the concentrated solutions A and B are varied over the course of time in such a way that the concentration of the second 35 substance B in the diluted solution varies over the course of time in accordance with a predetermined profile.

According to another characteristic of the invention, the flowrate  $Q_0$  of the liquid in the conduit is constant, and the

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5 According to yet another characteristic of the invention,  
the injection flowrate Q1 and the injection flowrate Q2 of the  
concentrated solutions A and B are varied over the course of  
time in such a way that the concentration of the first  
substance A in the diluted solution varies over the course of  
10 time in accordance with a predetermined profile.

- a conduit with a first end intended to be connected to  
15 a source of liquid, such as water, and a second end for  
delivering a treatment liquid;

- second injection means for injecting into the conduit, at a flowrate Q2, a second concentrated solution containing the first ionic substance A and the second ionic substance B, the first ionic substance A having, in the second concentrated solution, the same concentration [Asol] as in the first concentrated solution, and the second ionic substance B having, in the second concentrated solution, a second concentration [B2sol] different than the first concentration [B1sol] in the first concentrated solution;

- regulating means for regulating the first and second injection means and for adjusting the injection flowrate Q1 and the injection flowrate Q2 of the first and second concentrated solutions in such a way that at any given time the diluted solution resulting from the mixing of the liquid and the concentrated solutions has a desired concentration [Ades] of first substance A and a desired concentration [Bdes]

of second substance B.

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In one embodiment of the invention, the device for preparing treatment liquid is incorporated in a hemodialysis system, the substance A is sodium and the substance B is potassium, calcium, or magnesium. As the sodium concentration in a dialysis liquid is much higher than the potassium (calcium or magnesium) concentration, the potassium concentration can be very precisely regulated by measuring the conductivity of the mixture forming in the conduit immediately downstream of the site of injection of the first concentrated solution into the conduit, and of the mixture forming in the conduit immediately downstream of the site of injection of the second concentrated solution into the conduit (there is an excellent correlation between the conductivity of a solution and its sodium concentration).

Moreover, there is no danger of influencing the plasma potassium or calcium concentration of a patient using a very dilute dialysis solution prepared and administered by a system equipped with reliable means for measuring concentrations, which would not be the case if this objective were achieved by injection of more concentrated solution.

The invention also relates to a kit of solutions for extracorporeal treatment of blood, comprising two concentrated solutions and a bag with two compartments intended to contain each of the solutions from the kit. Each of the solutions contains at least two ionic substances A and B, the ionic substance A having the same concentration in the two solutions and the ionic substance B having different concentrations in two solutions.

According to one characteristic of the invention, the two solutions are identical except for one ionic substance whose concentration differs from one solution to the other.

Other characteristics and advantages of the invention will become more apparent on reading the following description. Reference will be made to the attached drawings, in which:

Figure 1 is a diagram showing a device for treatment of blood;

Figure 2 shows a bag with two compartments for containing the two concentrated solutions from a treatment kit; and

Figure 3 is a graph showing several profiles of variation in the potassium concentration of a dialysis liquid.

5        The hemodialysis system shown in Figure 1 comprises a hemodialyzer 1 with two compartments 2, 3 separated by a semipermeable membrane 4. A first compartment 2 has an inlet connected to a blood withdrawal conduit 5 on which a circulation pump 6 is arranged, and an outlet connected to a  
10       blood return conduit 7 on which a bubble trap 8 is interposed.

      An infusion device comprising a pump 10 and a balance 11 is provided for injecting into the bubble trap 8 the contents of a bag 9 of infusion liquid containing sodium bicarbonate. The bag 9 is suspended from the balance 11 and it is connected  
15       to the bubble trap 8 via a conduit 12 on which the infusion pump 10 is arranged. The balance 11 serves to control the pump 10 so that the flowrate of the infusion liquid is equal to a reference flowrate.

      The second compartment 3 of the hemodialyzer 1 has an  
20       inlet connected to a conduit 12 for supply of fresh dialysis liquid, and an outlet connected to a conduit 13 for removal of spent liquid (dialysis liquid and ultrafiltrate).

      The supply conduit 12 connects the hemodialyzer 1 to a device 14 for preparing dialysis liquid, comprising a main  
25       conduit 15 whose upstream end is intended to be connected to a source of running water. First and second subsidiary channels 16, 17 are connected to this main conduit 15.

      According to the invention, the free end of the first subsidiary conduit 16 is intended to be immersed in a  
30       container 18 for a first concentrated saline solution containing sodium chloride, calcium chloride, magnesium chloride and potassium chloride. This first conduit 16 is equipped with a pump 19 for metering the first concentrated solution into the dialysis liquid, which is controlled as a  
35       function of the comparison between 1) a first reference value of conductivity for the solution forming at the junction of the main conduit 15 and the first subsidiary conduit 16, and 2) the value of the conductivity of this solution measured by

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means of a first conductivity probe 20 arranged on the main conduit 15 immediately downstream of the junction between the main conduit 15 and the first subsidiary conduit 16.

According to the invention, the free end of the second subsidiary conduit 17 is intended to be immersed in a container 21 for a second concentrated saline solution containing sodium chloride, calcium chloride, magnesium chloride and potassium chloride. This second solution contains the same ionic substances as the first solution and in the same concentrations, except for potassium whose concentration is different. The second conduit 17 is equipped with a pump 22 for metering the second concentrated solution into the dialysis liquid, which is controlled as a function of the comparison between 1) a second reference value of conductivity for the solution forming at the junction of the main conduit 15 and the second subsidiary conduit 17, and 2) the value of the conductivity of this solution measured by means of a second conductivity probe 23 arranged on the main conduit 15 immediately downstream of the junction between the main conduit 15 and the second subsidiary conduit 17.

The conduit 12 for supply of dialysis liquid forms the continuation of the main conduit 15 of the device 14 for preparation of dialysis liquid. Arranged on this supply conduit 12, in the direction of circulation of the liquid, are a first flowmeter 24 and a first circulation pump 25.

The downstream end of the conduit 13 for removal of spent liquid is intended to be connected to the drain. Arranged on this conduit, in the direction of circulation of the liquid, are a probe 26 for measuring the potassium concentration, a second circulation pump 27, and a second flowmeter 28. An extraction pump 29 is connected to the removal conduit 13 upstream of the second circulation pump 27.

The hemodialysis system represented in Figure 1 also comprises a calculation and control unit 30. This unit is connected to a screen 31 and to a keyboard 32 via which the user inputs various reference values: flowrate reference values (blood flowrate  $Q_b$ , dialysis liquid flowrate  $Q_d$ , infusion solution flowrate  $Q_{inf}$ ), reference values for

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concentration of ionic substances in the dialysis liquid, reference value for the duration of treatment T, reference value for loss of weight WL. Moreover, the calculation and control unit 30 receives information emitted by the measurement elements of the system, such as the flowmeters 24, 28, the conductivity probes 20, 23, and the probe 26 for measuring potassium concentration. As a function of the instructions received and of programmed operating modes and algorithms, it controls the drive elements of the system, such as the pumps 6, 10, 19, 22, 25, 27, 29.

According to the invention, the concentration of sodium and the concentration of potassium in the dialysis liquid can be adjusted independently of one another: for a constant flowrate Q0 of water, the concentration of sodium depends on the sum of the flowrate Q1 of the first concentrated solution injected via the pump 19 into the main conduit 15 and the flowrate Q2 of the second concentrated solution injected via the pump 22 into the main conduit 15, while the concentration of potassium depends on the ratio of the flowrates Q1, Q2 of the first and second concentrated solutions. The concentration of sodium and of potassium in the dialysis liquid is chosen as a function of each individual patient. It can be set at a fixed value. According to the invention, for patients with hyperkalemia, the potassium concentration of the dialysis liquid is modified continuously during the treatment session according to a predetermined profile of variation.

#### Example:

The hemodialysis system described above is equipped with a bag 50 made of flexible transparent plastic, as is represented in Figure 2, and comprising two compartments 51 and 52 corresponding respectively to the containers 18 and 21 in Figure 1. The bag 50 is provided in its upper part with eyelets 53 by which it can be suspended vertically from a suitable support. Each compartment 51, 52 is equipped at its base with an access tube 54, 55 provided at its end with a connection element 56, 57 intended to cooperate with a complementary connection element fixed to the end of the subsidiary conduits 16, 17 of the device 14 for preparation of



dialysis liquid. A clip 58, 59 is arranged on each of the tubes 54, 55.

The compartment 51 (container 18) contains the following substances, in the following concentrations:

- 5        NaCl: 284.31 g/l
- KCl: 19.57 g/l
- CaCl<sub>2</sub>: 10.29 g/l
- MgCl<sub>2</sub>: 2.63 g/l
- Anhydrous glucose: 35 g/l.

- 10       The compartment 52 (container 21) contains the following substances, in the following concentrations:

- NaCl: 284.31 g/l
- KCl: 0 g/l
- CaCl<sub>2</sub>: 10.29 g/l
- 15       MgCl<sub>2</sub>: 2.63 g/l
- Anhydrous glucose: 35 g/l.

- By means of these two solutions it is possible, according to the invention, to prepare a dialysis liquid having a sodium concentration of between approximately 130 mEq/l and
- 20       approximately 155 mEq/l, and a potassium concentration varying, during a treatment session, from between an initial value of approximately 2.5 mEq/l and approximately 5.5 mEq/l and a final value of between approximately 1 mEq/l and approximately 2 mEq/l.

- 25       Figure 3 shows four profiles of variation of the potassium concentration of a dialysis liquid, which profiles can be obtained using the device 14 for preparation of dialysis liquid connected to the bag 50 with two compartments containing the concentrated solutions which have just been
- 30       described. In this figure, the broken line shows the constant potassium concentration of a conventional dialysis liquid, that is to say 2 mEq/l.

The hemodialysis apparatus which has just been described functions in the following manner.

- 35       An operator inputs to the control unit 30, via the keyboard 32, conventional reference values corresponding to the various parameters of treatment (prescription), namely the blood flowrate  $Q_b$ , the dialysis liquid flowrate  $Q_d$ , the

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infusion flowrate  $Q_{inf}$  of the bicarbonate solution, the total weight loss WL (quantity of plasma water to be withdrawn from patient by ultrafiltration), the total duration T of the session, and the sodium concentration of the dialysis liquid.

5        According to the invention, the operator also inputs, to the control unit, an information item or a series of information items concerning the potassium concentration of the dialysis liquid, which can be either a fixed reference value or one of the variation profiles stored beforehand in  
10 the control unit, corresponding for example to one of the graphs in Figure 3. The operator can also create and store a profile appropriate to an individual client.

      According to an alternative embodiment of the invention, the potassium concentration of the dialysis liquid is adjusted  
15 via the control unit 30 in the following manner: a dialysis liquid having a potassium concentration corresponding to a predetermined reference value is initially circulated in the hemodialyzer 1, and this reference value is compared with the value of the potassium concentration in the spent liquid,  
20 measured by the probe 26. The control unit 30 subsequently controls the pumps 19, 22 of the device 14 for preparation of treatment liquid in such a way that the difference between the reference value and the measured value remains substantially equal to a given value, corresponding to a difference,  
25 acceptable for the patient, between the potassium concentration of the plasma and that of the dialysis liquid.

      After a kit of concentrated solutions, such as the bag described above, has been connected to the conduits 16, 17 of the device 14 for preparation of dialysis liquid, the dialysis  
30 liquid circuit is filled with dialysis liquid. To do this, the main conduit 15 is connected to a source of running water and the pumps 19, 22, 25, 27 are started up. The pumps 19 and 22 are regulated via the control unit 30 in such a way that the potassium concentration and the sodium concentration of the  
35 dialysis liquid are equal to the corresponding reference values. The pumps 25, 27 for circulating dialysis liquid are regulated via the control unit 30 in such a way that the flowrate of the pump 25 situated upstream of the hemodialyzer

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1 is equal to the reference flowrate  $Q_d$  (500 ml/min, for example) and so that the flowrate of the pump 27 situated downstream of the hemodialyzer 1 is such that the flowrates measured by the flowmeters 24, 28 are equal.

5 At the same time as the dialysis liquid circuit is filling with the dialysis liquid according to the prescription, the circuit for extracorporeal blood circulation is rinsed and filled with sterile physiological liquid.

When priming of the dialysis liquid circuit and of the  
10 blood circuit is completed, the blood circuit is connected to the patient and the treatment proper can commence: the pumps 19, 22 of the device 14 for preparation of dialysis liquid, and the pumps 25, 27 for circulating the dialysis liquid, continue functioning, while the blood pump 6, the extraction  
15 pump 29 and the infusion pump 10 are started up. The blood pump 6 is set at the reference flowrate  $Q_b$  (for example 200 ml/min), the infusion pump 10 is set at the reference flowrate  $Q_{inf}$ , and the extraction pump 29 is set at a flowrate  $Q_{UF}$  calculated by the control unit 30 on the basis of the  
20 reference values for total weight loss  $WL$ , infusion flowrate  $Q_{inf}$  and total duration of treatment  $T$ .

The invention which has just been described is open to variants.

In the same way as the potassium concentration, the  
25 calcium or magnesium concentration can be adjusted to the needs of each individual patient.

With the preparation device according to the invention, it is possible to simultaneously adjust the potassium concentration of a dialysis liquid according to a first  
30 defined variation profile and the sodium concentration of the same dialysis liquid according to a second defined variation profile.

A probe for measuring the potassium concentration can be mounted on the supply conduit 12 in order to provide a  
35 measured value of the potassium concentration which will be used, for example, to calculate the difference between this value and the value measured downstream of the hemodialyzer 1 by the probe 26.

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